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ELICITING EXPERT KNOWLEDGE IN A DESIGN ACTIVITY : SOME METHODOLOGICAL ISSUES

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Eliciting expert knowledge in a design activity: some methodological issues

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Recueil et analyse de l'expertise dans une activité de conception: questions de méthode

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PROGRAMME 8

Abstract. Describes a study of expertise in a situation in which the problems processed are ill-structured (design activity) and in which the expert cannot be studied during problem processing (because of time constraints). Existing methods for knowledge elicitation have been developed for well-structured problem-solving, and are therefore not always well-suited to ill-structured problem-solving in time constrained situations.
Different methodological aspects are presented: the elicitation techniques developed and used, the formalisms chosen for knowledge representation (mainly objects and production rules), the kind of results obtained (types of knowledge and of expertise), the difficulties met using the techniques (naïve questioning, incompleteness of the knowledge inventory) and their consequences for the validity of the results.

Keywords: Expertise, Expert knowledge elicitation, Data gathering techniques, Design activity, Knowledge representation

Résumé. Les méthodes de recueil d'expertise existantes sont peu adaptées aux cas où les problèmes traités sont mal structurés et où l'expert ne peut être étudié dans le cours même de son activité. Différents aspects méthodologiques relatifs au recueil et à l'analyse d'une expertise dans une telle situation sont présentés: techniques de recueil développées et utilisées, formalismes choisis pour la représentation des connaissances (principalement objets et règles de production), résultats obtenus (types de connaissances et d'expertise), difficultés soulevées par le recueil (questionnement naïf, inventaire incomplet des connaissances) et leurs conséquences pour la validité des résultats.

Mots clefs: Expertise, Recueil de connaissances, Techniques de recueil de données, Activité de conception, Représentation de connaissances

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Contents

Knowledge aquisition is often considered to be a bottleneck of knowledge transfer, whether the supposed beneficiary of this transfer is another human or an expert system (see Kidd, 1987, in which a variety of elicitation methods are presented). Psychologists, because of their experience in observation methods and data analysis, should be able to contribute to the elaboration of an appropriate methodology in this domain.

Most of the methods now available come either from experimental psychology (and particularly from studies in problem solving), or human factors (work analysis). However, these two sources of methods quickly turn out to be inadequate in some real work situations, for two main reasons:

- on the one hand, existing methods have been developed for well structured problems (epitomized by the Tower of Hanoï problem), and rarely for ill-structured problems, such as, for example, design problems (see Bisseret, Figeac-Létang & Falzon, 1988);

- on the other hand, these methods assume that the subject can be observed <u>while processing the problem</u>, and consequently, that methods of direct observation or of simultaneous verbalization can be used (see the methods described by Visser & Morais, 1988). This is not always true: the activity may stretch over too long a period, and the time constraints of the study may be restricted, thus forbidding direct observation and simultaneous verbalization.

This paper presents a study of expert knowledge elicitation in which both of the above constraints are present: a design activity was studied, in conditions which did not allow the activity to be studied using direct observation methods. The goal of this text is to describe the techniques which have been used during elicitation in this specific situation. We discuss the types of results that have been obtained and the problems met during the study.

1. METHOD

1.1 <u>A presentation of the expertise under study</u>

The expertise under study concerns the "preparation of elements in compound materials", that is the definition of the procedures to be used for the production of a new piece made up of this type of very light and strong material.

Several observations bring us to classify the preparation of elements in compound materials as a design activity:

- the expert does not solve the problems he processes by following a standard, pre-existing method. Although some factors are always taken into account and play an important part in the reasoning process (e.g. the structure of the element: does the piece have a sandwich or a monolithic structure[1]?), the order in which they are taken into account varies.

- the definition of the problem does not precede processing. First, because the data initially available to the expert are, in general, incomplete: the client, or colleagues, will provide more information later. Secondly, because the expert participates in the definition of the constraints: up to a certain extent, he may choose to respect a given aspect and/or to modify another one.

- lastly, according to the experts, a given problem does not have a single solution, but a class of acceptable solutions.

These three observations are characteristic of an opportunistic processing, typical in design activities (see Visser, in press). Also, as often is the case in design, processing requires an interaction with colleagues upstream (here, the designers of the Research Department), and downstream (the craftsmen of the workshop) (see Visser, 1987). The study reported here does not deal with this (important) aspect of the activity, but focuses on the expertise of the "preparer".

The goal of the study was to "save" the knowledge of an expert preparer. As the expert was about to retire, and because he was supposed to concentrate on this study, he was not given new problems to handle. This forbids the use of direct observation methods, such as observing the real design activity.

The study thus concerned a single expert ("the" expert, in this text). However, some other experts were also consulted, in order to adjust our results and to study some methodological issues.

All sessions were tape-recorded and transcribed. The expert's graphical productions (annotated plans, explanatory drawings, etc.) and textual productions (texts written in preparation of a session, syntheses) were collected.

1.2 Data gathering

Expertise in a domain lies in particular in the way in which an expert uses his knowledge, that is in his reasoning. Reasoning calls for various types of knowledge, which in turn use various domain-specific concepts.

For methodological reasons, data gathering was split in two steps, for which different techniques were used:
• concepts description
• description of the knowledge units in the way they are used during reasoning.
These two steps have a different focus. However, if an element of reasoning appeared in the first step, we collected it. No new concept was discovered in the second step.

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[1] "Sandwich" and "monolithic" refer to types of compound structures.

1.2.1 Concept description

1.2.1.1 Global description of the task (semi-directed interviews)

In a first approach of a new domain, this method makes it possible to grasp the main characteristics of the task and the main steps in the expert's activity (for more methodological details, see Visser & Morais, 1988).

This method allows the concepts to be collected by means of questions on

- the products that the expert has to know about
- his interventions on these products
- the sources of information he calls for
- the results of his activity

1.2.1.2 Problem categorization

The expert is requested to provide a sample of problems handled in the past, so that all possible problem types are represented.
The goal is to collect problem types and to analyze the ways in which problems differ from the standpoint of processing difficulty for the preparer (not the ways in which solutions differ, that is, for example the processes or materials being used).

1.2.1.3 Detailed description of the concepts

When a list of the concepts used by the expert becomes available, the expert is requested to describe the main characteristics of the entities covered by these concepts (e.g. elements, materials, processes), and to provide examples.

1.2.2 Description of the reasoning processes

During the collection of the reasoning processes, special attention must be paid to collecting the justifications underlying the knowledge units used by the expert. Justifications are of course necessary for tutoring situations (see Clancey, 1983). An additional reason is that many knowledge units used by the expert are either normative or practical, that is based on a state of affairs, on experience, or on technical know-how. These bases may change, which affects the validity of the knowledge units. Their underlying justifications would therefore be useful for updating the knowledge base.

1.2.2.1 Comments about past problems (handled by the expert)

An analysis is made of the documents used or elaborated by the expert during the processing of design problems handled in the past. The expert is requested to explain the reasons that led him to each design decision he took.

While this method gives access to the expert knowledge, it does not make it possible to know for sure *how* this knowledge is *used, in actual processing* (in particular, there is a tendency for rationalization; see Ericsson & Simon, 1984).

1.2.2.2 Comments about new problems (handled by colleagues)

The observation of the expert during his activity, that is the study of design projects "in real time", is probably the most appropriate way to collect data about the reasoning processes actually used during processing, even if the necessary length of the observation (and, next, of its analysis) makes it a costly method (see Visser, 1987, 1988; Visser & Morais, 1988).
For reasons given above (see §1.1), this method could not be used. The expert was therefore requested to reason about problems that had been handled by colleagues.

1.2.2.3 Comments about modifications in manufacturing procedures

In general, when a piece must be made several times, the manufacturing procedures evolve with each successive version. The explanation by the expert of the reasons that have led to these modifications reveals criteria used when designing procedures.

1.2.2.4 Comments about fault forms

Fault forms describe problems which have occurred and the solutions that have been found. Having the expert comment on these forms makes it possible to collect aspects of the expertise which might have been missed by the other methods. In particular, these knowledge units may be necessary to understand some criteria presented without justification or not mentioned.
This technique is close to the analysis of faults or "critical incidents analysis", used in human factors studies.

1.2.2.5 Confrontation of different levels of expertise

The knowledge of the expert must be differentiated from the knowledge of the novice, especially as concerns the reasoning processes. So, a comparison of problem processing by the expert and by a novice provides indications on the nature of expertise.

This point has been studied in a session in which a novice presented the expert with the solution he had elaborated for a new problem. The expert had to analyze the solution and to provide (if necessary) criticisms, suggestions, etc.
This method corresponds in fact to a natural work situation.

1.2.2.6 Confrontation of different types of expertise

Different domains. In the same way, relevant information may appear in a discussion between two experts in different domains about a project in which both have to intervene.
This method has been used in organizing a discussion between the expert and a colleague (expert in a different domain) who intervened in a preceding step of design.

Same domain. The justifications underlying the knowledge units pertain, in part, to the expert's experience in his domain. Experts in the same domain, but with different experience, may thus have access to different justifications (and consequently to different knowledge units).
A second expert in the preparation domain was then requested to

accomplish a task that had also been proposed to the first expert, problem categorization (see §1.2.1.2)[2]. We focused on collecting his underlying justifications.

2. RESULTS

2.1 Object-oriented formalization of the concepts

An object-oriented formalism was chosen for the concepts, that is a schematic representation in which a concept, the central element of the object, is defined by means of attribute-value pairs.

For each concept, an object was created, describing it little by little using the attributes that the expert mentioned or for which he provided values. The annex presents an example of a concept described in this way.

Most concepts are considered by the experts as a sub-class of a more general class, itself often being a sub-class of another class. About 100 concepts have been described, and can be grouped in ten classes.

2.2 Representation of the knowledge used in processing

2.2.1 The choice of a formalism

The reasoning processes of the expert have been decomposed in order to spot the knowledge units that were used and the way in which they related.

According to the type of knowledge, representation formalisms are more or less appropriate. The object formalism, allowing various conceptual structures to be represented (such as "script", "schema", or "prototype"), appeared to be adequate for representing concepts. The production rules formalism (if condition - then action) makes it possible to describe accurately many knowledge units appearing in the expert's reasoning.

Here is an example of a knowledge unit verbalized in a way consistent with this formalism:

(1) If many forces have to go through an element, the element must be monolithic.

Other utterances may be translated in this formalism, with little risk of attributing knowledge units to the expert which he does not possess. For example, the utterance

(2) According to the thickness of the nida[3], it may be necessary to shape it.

may be translated (considering its context) in

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[2] In the text, we will use the terms "expert-1" and "expert-2". The expert-1's past experience came from the workshop, the expert-2's past experience came from the laboratory.

[3] Type of material.

(2') If the thickness of a nida is superior to x, it is necessary to shape it; otherwise, it is not useful.

However, the production rule formalism is less suited for translating other knowledge units, especially when they express absolute criteria. Here is an example of this kind of knowledge:

(3) Decomposing an element in smaller parts must be avoided.

For all knowledge units, the representation that remained the closest to the verbalization was chosen.

2.2.2 Classification of the knowledge units

Even though the goal of the study was not to model the design activity, the analysis was guided by some ideas on that subject In particular, the opportunistic nature of problem processing has led, as concerns the organization of the knowledge units, to finding inspiration in the blackboard models often used to describe opportunistic reasoning (see Bisseret, Figeac-Létang & Falzon, 1988; Nii, 1986; Visser, in press).

Knowledge units were therefore organized in eight classes as a function of the question of the preparer to which they provide an answer. These questions appear in all design projects in the domain, as for instance the question underlying an example given above (concerning the structure of the material: does the piece have a sandwich or a monolithic structure?) or the question of the interfaces (where should the junctions between subparts of an element be located? what type of junction should be used?).

3. DISCUSSION

3.1 Types of knowledge and types of expertise

3.1.1 Declarative knowledge and procedural knowledge

A same knowledge unit may be used in different ways. According to its uses, its verbalization by the expert and its translation into a representation formalism will vary. For instance, the same knowledge unit underlies (4), declarative form, and (4'), procedural form:

(4) Forces do not go through bolts that are loose; forces go through bolts that are tight

and

(4') In order for the forces to go through bolts, the bolts must be tight.

Utterance (4) can be found in a description of various types of bolts, or in the explanation of the reasons why a given type of bolt was used to join two parts.

Utterance (4') is a translation of the knowledge unit in a form adapted to its use by an operator wishing to have forces go through two parts joined with bolts.

3.1.2 General rules and exceptions

A type of knowledge organization we met several times is the following. The expert uses, on the one hand, a general rule, such as "Always X" (in which "always" is often omitted), and, on the other hand, an exception to this rule "If conditions C, then not-X".

Here is an example. The expert is presenting the nida (see footnote 3), and differentiates, as concerns its use, between metal nida and non-metal nida. He says that

(5) Bits of metal nida that have to be assembled must overlap.

Later, when presenting a specific case, the expert does not feel it contradictory to say:

(6) For an element made in "cocuisson"[4], it may be impossible to overlap bits of metal nida.

When requested, the expert is able to explain the reasons of this impossibility.

Exceptions set two types of problems:

- on the one hand, the psychologist can hardly be sure that all the exceptions have been spotted: it might be that, in some cases, only the general rule has been elicited;

- on the other hand, from the standpoint of implementing this knowledge into a program, a problem of consistency may arise.

However, it is to be stressed that exceptions do not mean that the expert is inconsistent, but that he has organized his knowledge in an economical way. The "general" rule is in fact a "default" rule: if no other, more specific condition exists, it is applicable.

3.1.3 Knowledge of the "address"

Some knowledge units of the expert refer to external sources of information. The expert knows that if such information is needed, it may be found in such a place. An instance concerns the different types of resins. The expert knows the classes of resins, and even some sub-classes, but does not know their exact references. However, he knows exactly in which document he can find the information.

3.1.4 Knowledge outside the domain of expertise

Although the expert is expert only in a specific domain, this does not mean that he has no knowledge outside his domain of expertise. This "outside" knowledge often does intervene in the justifications he provides for expert knowledge units.

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[4] Type of process.

Knowledge of a link, but not of its justification. The expert may know something, but not its justification, which in fact he does not need to know: the choices and decisions he has to take will never require his awareness of this justification.

For example, he knows that a given resin is particularly appropriate for "cocuisson" (see footnote 4), but does not know why.

Knowledge of a link, but only of a partial justification is sometimes all the knowledge that the expert possesses about the relationship between two entities.

The expert knows, for example, that

(7) The resin rate required for an element depends on the mechanical qualities sought,

but would not be able to determine these mechanical qualities, nor to evaluate, according to these, the resin rate. Again, this is outside his domain of competence.

3.1.5 Types of expertise: operative knowledge and general knowledge

The comparison of the data gathered with the two expert preparers (see §1.2.2.6) indicates the existence of different types of expertise (in the same domain).

We have observed:

- a "natural" categorization with expert-2, when no (explicit or implicit) categorization could be obtained from expert-1;
- an abstract categorization with expert-2, who situates the problems he presents in categories identified by general terms; expert-1 uses a concrete categorization, by searching for the parent problem;
- a more extensive categorization by expert-2 than by expert-1 (however, it is to be noted that this larger coverage is obtained by the expert-2 presenting classes that have not been used for a long time - if they have ever been used at all);
- different types of justification of the knowledge units: expert-1 provides practical justifications, expert-2 provides technical justifications.

Table 1 presents the categorization presented by expert -2 for "structures de révolution" (circular structures)[5]. The categories that had been exemplified by expert-1 appear italicized.

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[5] Because of the technical nature of the terms used in Table 1, we do not translate them.

Structures de révolution
monolithique
tôle épaisse
tôle fine
auto-raidie par drapage en ondulation
raidie par raidisseurs collés
raidie par raidisseurs drapés (en U)
sandwiches
symétriques
asymétriques

Table 1. The classification of "structures de révolution" (circular structures) by expert-2

The origin of these differences bteween the two experts may stem from the nature of their past professional experience (that is, of their past domain of competence). We will use here the distinction (made by Ochanine, 1978) between "operative image" and "cognitive image".

Expert-1 comes from the workshop. His knowledge has been acquired through experience (and not through a theoretical education). His knowledge is thus structured by the problems he has had to face, to which new problems are compared: he uses an <u>operative knowedge</u>.

Expert-2 on the other hand would have a <u>general knowledge</u>, less structured by past problems than by general elements of domain knowledge ("general" in the sense of: not applied, independent of the past problems). New problems would then be classified as instances of an abstract category.

3.2 <u>Difficulties met in data gathering</u>

3.2.1 Questions beyond the limits of the expertise domain

The analyst may experience difficulty in circumscribing the domain of competence of the expert. Since she/he does not know the domain (at least initially!) and tries to obtain the justifications of the expert knowledge units, he/she has to ask many questions about design decisions. When the justification remains within his domain of competence, the expert is, in general, able to answer.

However, a justification may require elements of knowledge outside the expert's domain of competence. In some cases, the expert knows (sometimes partly) the justifications of his reasoning: he possesses elements of knowledge peripheral to his own domain of competence (see §3.1.4).

In other cases, the expert does not know the justifications of the rules he uses. He may then either state it (e.g. in utterances like "That is the way it is"), or attempt to build up a justification: this may give birth to naïve physics explanations, or to inconsistent results (the expert justifies X by Y, but Y has no link with X; or he justifies X once by Y, then by Z).

In many cases, the analyst will be able to detect these erroneous justifications only if they go against logic. Concerning the expert's naïve physics, the analyst may only suppose its existence. It may in fact be the case that the expert creates naïve physics for the sake of the analyst. Naïve physics may be an answer adapted to naïve questioning!

Erroneous elements may then be included in the knowledge base.

3.2.2 Incomplete knowledge inventory

The expert often uses terms such as "sometimes", "generally", etc. which indicate a restriction in the application of the utterance, but he often fails to specify precisely the limits of its validity. If the analyst immediately detects these restrictions, he/she may ask the expert to be more precise as to the conditions of application. Sometimes, restrictions are only spotted when analyzing the data. If the expert is no longer available (as was the case at the end of the analysis stage of our study), the analyst will not be able to fill in the missing information, and will not know if the expert had access to the missing information or if his knowledge was "imprecise" on this point.

3.2.3 The validity of elicited knowledge

The difficulties described above set the general problem of the validity of the elicited knowledge. The analyst faces several difficulties:

- precise circumscription of the expert's domain of competence
- identification of the interest of the elicited information: For the analyst, all elements of knowledge are new. It is therefore difficult to distinguish the trivial knowledge units from those that pertain to the expert knowledge.
- error identification: Various sources, some of which have been described earlier, may lead to errors subsisting in the resulting knowledge base: inclusion of incomplete or wrong justifications, omission of exceptions to rules, erroneous interpretation (by the analyst) of expert's comments, etc.
- identification of the omissions: The analyst may very well omit a sub-domain of competence, if the expert does not mention it.

Two solutions to these problems can be thought of:

Multiplication of the experts. If several experts in the domain are available, the comparison of their verbalizations may make it easier to spot the inconsistencies. Furthermore, the consultation of multiple experts will minimize the risks of omission of a sub-domain of expertise and will allow some exceptions to the rules to be identified.

Assistance by a domain-competent colleague of the expert. Another method consists of collecting data in collaboration with a domain-competent colleague of the expert. This colleague's knowledge may be theoretical (e.g. a newly qualified novice) or general (e.g. a supervisor). This assistance may make it possible to limit the questioning to the expertise domain, to identify trivial knowledge and expert knowledge, and to spot erroneous interpretations.

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ANNEX - Example of an object with its attributes: "résine" (resin)[6]

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Résine
    composition
        résine seule
        résine avec adjuvant
            résine avec colorant
            résine avec charges
            résine avec renforts
            résine avec catalyseur
    types
        Epoxys
            BSL312 à 120°
            BSL319 à 120°
        Phénoliques
        Polyamides
        Gel coat
            effet
                dureté surface
                éventuellement: coloration surface
            utilisation
                surtout: moulage au contact à froid
            fonctions
                protection du moule et de l'agent de démoulage
                protection de la pièce finie contre eau
                éventuellement: coloration surface
                éventuellement: renforcer la tenue à l'abrasion
    caractéristiques
        retrait
            époxy: faible
            polyester: important
        tenue en température
        propagation en feu
        dégazage
    classes selon température de polymérisation
        température ambiante (18 à 20°)
        120°
        170°
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[6] Because of the technical nature of the terms used, we do not translate them.